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Project Title:

Postharvest Disinfestation of Horticultural Commodities: Controlled Atmospheres as an Alternative to Methyl Bromide

Summary: Recent advances in marine container technology improves the ability to conduct controlled atmosphere quarantine treatments during marine shipment. The work conducted with the support of this project has expanded our information base on insect mortality after controlled atmosphere treatments. At 0°C, high CO_2 atmospheres (45%) required 6 to 10 days to achieve 100% mortality of two-spotted spider mites. This treatment probably would not be feasible for strawberry fruit but may have application for other commodities for which two-spotted spider mites are of quarantine concern. High CO_2 atmospheres (75 to 100%) at 0°C to 10°C were effective in killing Western Flower thrips at 2 different life stages within 24 hours in one experiment, but up to 3 days were required in other experiments. Green peach aphids were effectively killed under conditions similar to those effective for Western Flower thrips. Many specialty leafy greens and asparagus can tolerate these high CO_2 atmospheres for the relatively short periods required to achieve complete insect mortality. Work on the quality of iceberg lettuce, a product less tolerant to high CO_2, to various atmospheres (low O_2 and high CO_2 combinations) is in progress. The tolerance of various cut flowers (orchids, carnations, chrysanthemums, roses and gladioli) to high CO_2 insecticidal atmospheres varied for the type of flower and the specific atmosphere. Sequential controlled atmospheres (very low O_2 followed by very high CO_2, or visa versa) are being explored for their potential as effective insecticidal atmospheres. Sequential or combination atmosphere treatments should be more benign for CO_2-sensitive products.

Postharvest Disinfestation of Horticultural Commodities: Controlled Atmospheres as an Alternative to Methyl Bromide

Results and Discussion:

A brief summary of results obtained to date by the 3 investigators involved in this project is presented. For reference and public discussion purposes, the main investigator responsible for each section of data is indicated.

Objective 1: Evaluate current controlled atmosphere technology for ability to establish and maintain insecticidal controlled atmospheres and propose modifications as necessary.

Consultations and demonstrations of equipment have occurred with Nitec Corporation. Nitec has a newly developed capability to strictly control and monitor both oxygen and carbon dioxide concentrations in marine containers. Compared with other systems available, this system has the ability to flush with nitrogen or carbon dioxide as needed to keep atmospheres within tightly controlled ranges. Simulated pre-transit and in-transit disinfestation treatments in commercial equipment are planned for spring-summer of 1997. We have also discussed combination or sequential treatments with Nitec and plan to conduct demonstration tests in marine containers during the coming year on location at the Port of Oakland.

Objective 2: Through large-scale implementation tests, demonstrate the feasibility of applying insecticidal controlled atmosphere treatments on a commercial scale.

Work on this objective was planned for Years 2 & 3.

Objective 3: Refine effective insecticidal controlled atmosphere treatments for Western Flower Thrips and Green Peach Aphids and develop protocols for Two-Spotted Mite.:

Two-Spotted Mite

The effect of high carbon dioxide atmospheres in air at 0°C was tested on two spotted mites, pests of strawberries and many other products. The higher the carbon dioxide concentration (from 50 to 95%), the greater the mortality (**Table 1**). Nearly 100% mortality of adults, protonymphs and larvae was achieved after 6 days of treatment at 80 to 95% carbon dioxide; however, 10 days at 65% carbon dioxide was required for 100% mortality. (Elizabeth Mitcham)

The effect of various oxygen concentrations together with 95% carbon dioxide on mite mortality was also tested (**Table 2**). There was little consistent effect of O_2 concentration on mortality when 95% carbon dioxide was also present. Complete absence of O_2 with 95% CO_2 tended to be less effective, particularly at longer exposure times. Absence of both gases (i.e., nitrogen atmosphere) was much less effective than high CO_2 and low O_2 atmospheres. (Elizabeth Mitcham)

In an effort to reduce the time needed for 100% mortality, two-spotted spider mites were treated at 20°C instead of 0°C (**Table 3**). Mites were exposed to either low oxygen or high carbon dioxide atmospheres or pure nitrogen atmospheres for 0.5, 2 and 4 days. All atmospheres were completely effective within 4 days, while the high carbon dioxide atmospheres gave better mortality after two days of treatment. Treatment with 65 and 95% carbon dioxide for two days gave nearly 100% mortality (**Table 3**).

For commodities shipped by marine container, the period of time at low temperatures during the voyage can be used to augment a short pre-transit treatment. Two-spotted mites were treated for one-half day at 20°C with low oxygen, high carbon dioxide or pure nitrogen. This short treatment was followed by an 18 day simulated voyage in air (**Table 4**) or 8% carbon dioxide (**Table 5**) at 0°C. When the pre-treatment was followed by shipment in air, the high carbon dioxide atmospheres were much more effective and the 95% carbon dioxide pretreatment was nearly 100% effective (**Table 4**). When the pre-treatment was followed by 8% CO2 at 0°C, all treatments resulted in nearly 100% mortality, including those mites not given a pretreatment. These results indicate that the 18 day treatment at 8% CO2 at 0°C was very effective. These treatments could be useful for floral products shipped by marine container.

We were successful at killing two-spotted mite. However, the treatment times were much longer than would be feasible for strawberry but might be useful for floral products. For this reason, fruit tolerance tests on strawberries have not been conducted at this time. Our next step is to try combining CO2 with volatile compounds such as ethanol and acetaldehyde to determine if mortality can be achieved more rapidly. (Elizabeth Mitcham)

Western Flower Thrips

Previous work on western flower thrips had indicated high mortality rates after relatively short exposure times to 80% CO2 (16 to 24 hours at 5°C) with an 8 hour recovery period prior to mortality assessment. Our more recent work, however, has failed to substantiate those earlier results. For accurate mortality assessment, it is necessary to allow the insects at least a 24 hour recovery period. With high CO2 treatments, at least 2 to 3 days is required at 95 to 98% CO2 at 0°C for 100% mortality (**Table 6**). Mortality occurred much more slowly at 65% CO2. (Marita Cantwell, Elizabeth Mitcham)

Green Peach Aphids

As with the western flower thrips, accurate assessment of mortality of green peach aphids requires about 24 hours for recovery. Reassessment of high CO2 atmospheres showed very high, but still incomplete mortality with 3 days at 95% CO2 at 0°C (**Table 7**). (Elizabeth Mitcham)

Sequential treatments for kill of Green Peach and Melon aphids and two-spotted mites

A series of sequential CA treatments (**Table 8**) were tested for effectiveness against Green Peach Aphids (*Myzus persicae*), Melon aphid (*Aphis gossypii*), and diapausing two-spotted spider mites (*Tetranychus urticae*). For the aphids, mortality of the control samples were very high and therefore the effectiveness of the treatments could not be accurately assessed. This work will be repeated at Cal Poly by Mark Shelton and colleagues once the CA lab is ready. For the two-spotted mites, mortality of the control arthropods was 6%. The highest mortality (32%) obtained by the sequential atmospheres was treatment 9 (0.1% O_2 for 2 days followed by 1 day 60% CO_2 followed by 3 days in air). Although these conditions are not as effective as the atmospheres used in Tables 1 and 2, the concept of using sequential atmospheres to achieve insect mortality is an important one and will be explored in future work. (Mark Shelton)

Objective 4: Determine the tolerance of the following products to insecticidal controlled atmosphere treatments: (a) strawberries, (b) cut flowers, (c) leafy greens

Strawberry: No quality tests have yet been conducted. (Elizabeth Mitcham)

Flowers:

Tolerance of Dendrobium orchids to high carbon dioxide controlled atmospheres was tested. Freshly harvested orchids were flown in from Hawaii. Orchids were exposed to 30% (4, 6 & 8 days), 45% (3, 5 & 7 days), 60% (1, 2 & 4 days) and 80% (0.5, 1 & 2 days) carbon dioxide in air at 13°C. All treatments reduced vase life relative to air stored flowers (**Figure 1**). Shorter treatments with high carbon dioxide concentrations had longer vase lives. The longest vase life for treated orchids was 10 days compared with approximately 18 days for untreated flowers. This treatment shows potential for insect quarantine. Insect mortality tests must now be conducted. (Elizabeth Mitcham)

The vase life of yellow carnation (Mediterranean Candy), orange Carnation (Mediterranean Candy), chrysanthemum (Minstral), rose (Gabriella) and Paphiopedilum Orchid (Sandrae) were tested after exposure to various sequential controlled atmospheres (**Tables 8 and 9**). Although the vase life was reduced by many of the CA treatments, some combinations resulted in vase life equal to or greater than the controls held in air or 4% O_2 + 4% CO_2. (Mark Shelton)

The quality of gladioli and carnations (white, red and mixed) treated with an average concentration of 75% CO_2 for 24 hours was very good. Vase life evaluations under naturally lighted conditions at 15-20°C (59-68°F) showed that development of flower buds on the gladioli was not affected by the CO_2 treatment. Open gladiolus flowers from the CO_2 treatment remained in good quality for at least as long as those of the control flowers. In the case of carnations, the flowers were treated when partially opened and open flower quality and vase life were at least as good as those of the untreated flowers. (Marita Cantwell).

Leafy Vegetables

Asparagus was treated with 40%, 75% or 100% CO_2 for up to 24 hours at 0, 10 or 20°C (32, 50 or 68°F) (**Table 10**). Spears were then stored at 5°C (41°F) for 7 days before evaluation for overall visual quality, decay and CO_2 injury and other parameters. Freshly harvested green spears (UC 157) tolerated very well treatments of 40% and 75% CO_2 for up to 24 hours at 0°C and 10°C. There were no important differences in other quality parameters (texture, off-odors, soluble solids and decay) between asparagus stored in air or treated with high CO_2 atmospheres. The atmospheres did slightly reduce typical asparagus aroma. Asparagus could also tolerate the treatments at 20°C for 18 hours, but quality was reduced with longer exposure. Work on asparagus was done with partial support from the California Asparagus Commission. (Marita Cantwell)

Leafy salad greens. We evaluated the tolerance of a wide range of specialty leafy greens (21 different products) to high CO_2 atmospheres. Ten types of lettuce including radicchio, spinach and chards, and several Brassica greens were evaluated. **Table 11** exemplifies the results obtained with the most tolerant leafy greens (mostly lettuces or other members of the Asteraceae, such as endive. **Table 12** shows typical results for the least tolerant leafy greens (in addition to red mustard, pak-choi and arugula did not tolerate high CO_2 at higher temperatures). All leafy products tolerated 80% and 100% CO_2 for up to 24 hours when applied at 0°C (**Table 13**). Most of the products also tolerated these atmospheres at 10°C, but after 24 hours some decrease in quality was often observed. Treatment at 20°C caused quality reductions in most of the specialty greens. Applying the insecticidal atmospheres over a reasonable temperature range of 0 to 10°C appears to be promising for many leafy greens. (Marita Cantwell)

Iceberg Lettuce. Work is in progress on iceberg lettuce. Compared to many other leafy greens, iceberg lettuce is known to be damaged by long-term exposure to CO_2 atmospheres. Heads are being treated with 80, 90 and 98% CO_2 insecticidal atmospheres at 0°C (32°F) and 10°C (50°F) for 24, 48 and 72 hours. In addition short-term high CO_2 treatments are followed by low O_2 atmospheres to improve efficacy and maintain lettuce quality. Brown stain and internal browning can result from high carbon dioxide atmospheres and visual evaluations focus on the appearance of these disorders. Lettuce is transferred to air at 0°C for 3 to 7 days before evaluation. Off-odor volatiles (ethanol and acetaldehyde) are also being analyzed after the treatment and transfer periods as indicators of abnormal metabolism. (Marita Cantwell)

Table 1. Percent mortality of two-spotted spider mites after treatment at 0°C (32°F) with various CO_2 concentrations in air.

% O_2	% CO_2	Duration, Days	Adults	Protonymphs	Larvae
21.0	0	2	6.72	20.88	22.78
10.5	50	2	34.04	31.25	0.00
7.35	65	2	19.15	21.88	11.11
4.20	80	2	26.45	34.36	29.48
1.05	95	2	6.72	30.01	64.49
21.0	0	4	16.62	27.55	65.56
10.5	50	4	43.46	52.65	76.85
7.35	65	4	43.00	57.15	75.56
4.20	80	4	74.35	71.77	77.51
1.05	95	4	89.80	82.43	97.70
21.0	0	6	12.13	18.33	25.71
10.5	50	6	59.16	75.19	88.53
7.35	65	6	81.17	83.85	96.25
4.20	80	6	99.13	99.72	100.00
1.05	95	6	99.80	100.00	100.00
21.0	0	8	19.62	41.48	50.00
10.5	50	8	90.25	95.59	100.00
7.35	65	8	98.76	100.00	100.00
21.0	0	10	23.11	29.92	17.19
10.5	50	10	99.56	100.00	100.00
7.35	65	10	100.00	100.00	100.00

Table 2. Percent mortality of two-spotted spider mites after treatment at 0°C (32°F) with 95% CO_2 in various O_2 concentrations.

% O_2	% CO_2	Duration, Days	Adults	Protonymphs	Larvae
21.0	0	2	8.52	15.92	23.37
0	0	2	8.73	25.90	45.86
0	95	2	48.57	40.39	56.34
0.05	95	2	24.46	34.07	45.20
0.5	95	2	12.99	20.98	27.04
1.05	95	2	24.91	30.01	64.49
21.0	0	4	7.45	13.45	42.06
0	0	4	12.29	21.33	50.00
0	95	4	91.22	88.92	95.83
0.05	95	4	94.03	82.98	100.00
0.5	95	4	93.76	82.51	100.00
1.05	95	4	89.80	82.43	97.70
21.0	0	6	8.53	17.47	22.66
0	0	6	55.91	52.32	92.35
0	95	6	99.62	99.39	100.00
0.05	95	6	99.80	100.00	100.00
0.5	95	6	98.07	100.00	100.00
1.05	95	6	99.80	100.00	100.00

Table 3. Percent mortality of two-spotted spider mite treated with selected atmospheres at 20°C.

time	% O2	% CO2	adult	deutonymph	protonymph
0.5d	air	air	3.13	10.56	11.35
	0	-	31.68	25.00	43.16
	0.5	-	15.07	10.43	22.91
	0.4	20	11.83	19.12	19.35
	air	65	15.14	15.60	30.77
	air	95	38.95	34.97	37.14
2d	air	air	8.60	6.25	10.87
	0	-	100.00	100.00	100.00
	0.5	-	69.47	60.19	76.42
	0.4	20	97.20	81.82	100.00
	air	65	100.00	97.50	100.00
	air	95	99.23	100.00	100.00
4d	air	air	10.20	18.42	16.80
	0	-	100.00	100.00	100.00
	0.4	20	100.00	100.00	100.00
	air	65	100.00	100.00	100.00
	air	95	100.00	100.00	100.00

Table 4 . Percent mortality of two-spotted spider mite treated with selected atmospheres for 0.5 days at 20°C followed by exposure to 18 days of air at 0°C.

time	% O2	% CO2	adult	deutonymph	protonymph
0.5d/18d	air	air	34.41	31.13	32.18
	0	-	87.93	89.42	94.32
	0.5	-	36.89	23.71	30.68
	0.4	20	40.22	35.29	45.00
	air	65	52.73	69.70	66.00
	air	95	96.58	90.38	100.00

Table 5. Percent mortality of two-spotted spider mite treated with selected atmospheres for 0.5d at 20°C followed by exposure to 8% CO2 at 0°C for 18d.

time	% O2	% CO2	adult	deutonymph	protonymph
0.5d/18d	air	air	95.12	94.27	98.10
	0	-	98.94	99.22	100.00
	0.5	-	95.65	95.04	100.00
	0.4	20	97.93	97.93	100.00
	air	65	98.58	100.00	100.00
	air	95	97.58	100.00	100.00

Table 6. Percent mortality of western flower thrips adults after treatment with selected concentrations of CO2 in air at 0°C.

$\%CO_2$	1 day	2 day	3 day	4 day
air	13.01	19.42	16.07	13.27
65	10.38	33.70	66.04	92.86
95	65.35	79.41	95.50	100.00
98	60.12	95.05	100.00	100.00

Table 7. Percent mortality of green peach aphid after treatment with selected concentrations of CO2 in air at 0°C.

$\% CO_2$	1 day	1.5 day	2 day	3 day
air	18.28	76.40	27.59	39.32
80	52.02	75.14	77.78	76.47
95	60.98	98.29	89.90	98.78

Table 8. Atmospheres tested for simulated in-transit sequential CA disinfestation (conducted at Levin Research Centre, NZ). Atmospheres were tested at 0.5°C (33°F).

Treatment	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Control	Air	Air	Air	Air	Air	Air
Control 2	$4\% O_2$+ $4\% CO_2$	4 % + 4 %	4% + 4%	4% + 4%	4% + 4%	4% + 4%
3	$60\% CO_2$	Air	Air	Air	Air	Air
4	$60\% CO_2$	4% + 4%	4% + 4%	4% + 4%	4% + 4%	4% + 4%
5	$60\% CO_2$	$0.1\% O_2$	$0.1\% O_2$	Air	Air	Air
6	$60\% CO_2$	$0.1\% O_2$	$0.1\% O_2$	4% + 4%	4% + 4%	4% + 4%
7	$0.1\% O_2$	$0.1\% O_2$	Air	Air	Air	Air
8	$0.1\% O_2$	$0.1\% O_2$	4% + 4%	4% + 4%	4% + 4%	4% + 4%
9	$0.1\% O_2$	$0.1\% O_2$	$60\% CO_2$	Air	Air	Air
10	$0.1\% O_2$	$0.1\% O_2$	$60\% CO_2$	4% + 4%	4% + 4%	4% + 4%

Table 9. Vase life of cut flowers exposed to sequential controlled atmospheres at 0.5°C (33°F). After treatment, flower stems were recut and flowers were placed in a Floralife® solution at 20°C (68°F), 45% RH and 20 µEinsteins $\cdot M^{2} \cdot sec^{-1}$ illumination with a 12:12 hour light: dark photoperiod. Evaluations were conducted periodically up to 14 days.

		Vase Life, Days				
Treatment		Yellow Carnation	Orange Carnation	Chrysan-themum	Rose	Paphiopedilum Orchid
Control	Air	11	13.5	8.5	7	7
Control 2	$4\% O_2$+ $4\% CO_2$	10.5	11	8.5	7.5	12
3	$60\% CO_2 \rightarrow$ Air	9.5	9.5	7	6	4
4	$60\% CO_2 \rightarrow 4\%O_2+4\%CO_2$	10	8	7.5	5.5	7
5	$60\% CO_2 \rightarrow 0.1\% O_2 \rightarrow$ Air	6.5	3	3	4.5	5
6	$60\% CO_2 \rightarrow 0.1\% O_2 \rightarrow$ 4% + 4%	7.5	4	6.5	3.5	4.5
7	$0.1\% O_2 \rightarrow$ Air	7.5	5	9	3	9
8	$0.1\% O_2 \rightarrow 4\%O_2+4\%CO_2$	7	7.5	9.5	3.5	10
9	$0.1\% O_2 \rightarrow 60\% CO_2 \rightarrow$ Air	1.5	0	1.5	1	1
10	$0.1\% O_2 \rightarrow 60\% CO_2 \rightarrow$ 4% + 4%	0.5	0	1	1	1.5

Table 10. Insecticidal controlled atmosphere treatment of **asparagus**: visual quality after treatment plus 7 days at 5°C (41°F). The visual quality of the tip and stem of the asparagus were evaluated separately, and the lowest score for either part is reported in the table.

	Overall Visual Quality										
Treatment	0°C (32°F)				10°C (50°F)				20°C (68°F)		
	12	18	24 hrs		12	18	24 hrs		12	18	24 hrs
Air Control	8.4	8.3	8.2		8.0	8.3	8.1		8.2	8.4	8.5
40% CO_2	8.0	8.4	8.1		7.9	8.2	7.5		7.8	6.4	6.5
75% CO_2	7.8	8.2	8.2		8.0	8.3	8.2		7.7	7.1	7.6
100% CO_2	7.7	7.9	8.0		7.6	8.0	7.8		7.9	7.7	5.2

Visual quality was evaluated on a 9 to 1 scale, where 9=excellent, 7=good, 5=fair, 3=poor and 1=unuseable. A score of 6 was considered the minimum for marketability.

Table 11. The visual quality of **radicchio** after treatment with 80% and 100% CO_2. After treatment, product was stored 1 week in air at 5°C (41°F) plus 12 hours at 15°C (59°F) before evaluation.

Temp.	**Atmosphere**	**Visual Quality**[1]			**Injury**[2]			**Decay**[2]		
		8 hr	**12 hr**	**24 hr**	**8 hr**	**12 hr**	**24 hr**	**8 hr**	**12 hr**	**24 hr**
0°C	Air	9.0	8.8	8.7	1.0	1.0	1.0	1.0	1.0	1.0
	80% CO_2	9.0	8.8	8.8	1.0	1.0	1.0	1.0	1.0	1.0
	100% CO_2	9.0	8.7	9.0	1.0	1.3	1.0	1.0	1.0	1.3
10°C	Air	8.7	8.8	9.0	1.0	1.0	1.0	1.3	1.0	1.0
	80% CO_2	8.8	8.7	8.7	1.0	1.0	1.0	1.0	1.0	1.0
	100% CO_2	8.5	8.8	8.5	1.0	1.0	1.0	1.0	1.0	1.0
20°C	Air	8.7	8.8	8.8	1.0	1.0	1.0	1.0	1.0	1.0
	80% CO_2	8.7	8.7	8.2	1.0	1.0	1.3	1.0	1.0	1.3
	100% CO_2	8.7	8.7	8.3	1.0	1.0	1.0	1.0	1.0	1.3
	LSD .05	0.1			0.1			0.1		

[1] Visual quality was evaluated on a 9 to 1 scale, where 9=excellent, 1=unuseable. The stipled area shows treatment conditions which resulted in good quality marketable product.
[2] Injury and decay were evaluated on a 1 to 5 scale, where 1=none and 5=severe.

Table 12. The visual quality of **red mustard greens** after treatment with 80% and 100% CO_2. After treatment, product was stored 1 week in air at 5°C (41°F) plus 12 hours at 15°C (59°F) before evaluation.

Temp.	**Atmosphere**	**Visual Quality**[1]			**Injury**[2]			**Decay**[2]		
		8 hr	**12 hr**	**24 hr**	**8 hr**	**12 hr**	**24 hr**	**8 hr**	**12 hr**	**24 hr**
0°C	Air	8.3	8.3	8.0	1.0	1.0	1.0	1.0	1.0	1.0
	80% CO_2	7.2	7.2	7.2	1.0	1.0	1.0	1.0	1.0	1.0
	100% CO_2	7.2	7.3	6.3	1.0	1.0	1.3	1.0	1.0	1.0
10°C	Air	7.5	7.3	7.3	1.0	1.0	1.0	1.3	1.0	1.0
	80% CO_2	7.3	7.3	7.0	1.0	1.0	1.7	1.0	1.0	1.0
	100% CO_2	7.0	6.8	6.0	1.3	1.7	2.0	1.0	1.0	1.0
20°C	Air	6.8	6.7	3.7	1.0	1.0	1.0	1.0	2.0	2.0
	80% CO_2	6.8	6.7	4.3	1.0	1.0	1.0	1.0	1.7	2.3
	100% CO_2	6.5	6.2	3.7	1.0	1.0	1.0	1.0	1.7	2.0
	LSD .05	0.1			0.1			0.1		

[1] Visual quality was evaluated on a 9 to 1 scale, where 9=excellent, 1=unuseable. The stipled area shows treatment conditions which resulted in good quality marketable product.
[2] Injury and decay were evaluated on a 1 to 5 scale, where 1=none and 5=severe.

Table 13. Visual quality of specialty leafy greens treated with air, 80% or 100% CO_2 for 24 hours at 0°C, 10°C or 20°C (32°, 50° or 68°F). Products were transferred to air for 7 days at 5°C plus 12 hours at 15°C (59°F) before evaluation.

Visual Quality Score[2]

	Air			80% Carbon Dioxide			100% Carbon Dioxide		
	0°C	10°C	20°C	0°C	10°C	20°C	0°C	10°C	20°C
Lettuces and Relatives									
1. Red Oak	8.7	8.1	8.3	8.3	7.3	7.3	7.3	7.7	6.3
2. Brunia[1]	9.0	8.8	7.8	9.0	8.0	7.3	8.8	8.3	6.7
3. Lollo Rossa[1]	9.0	9.0	8.8	9.0	8.8	8.7	9.0	8.7	8.2
4. Green Leaf	9.0	9.0	8.2	9.0	8.8	8.0	8.3	8.3	7.8
5. Green Romaine	9.0	7.8	7.2	8.8	7.8	7.2	9.0	7.7	6.8
6. Red Romaine	9.0	8.8	8.7	9.0	8.7	7.5	9.0	8.2	6.7
7. Endive	8.0	7.5	6.7	7.7	7.2	6.0	7.8	6.8	6.3
8. Radicchio	8.7	9.0	8.8	8.8	8.7	8.2	9.0	8.5	8.3
AVERAGE	*8.8*	*8.5*	*8.1*	*8.7*	*8.2*	*7.5*	*8.5*	*8.0*	*7.1*
Spinachs/Chards									
9. Beet greens	8.0	8.0	6.7	7.5	8.3	7.0	6.2	6.7	4.0
10. Spinach	9.0	9.0	8.2	9.0	9.0	8.2	9.0	8.8	7.2
11. Green Chard	8.3	8.0	7.0	8.2	8.2	7.5	7.2	7.3	7.2
12. Red Chard	8.5	8.3	7.0	8.7	8.2	7.2	8.3	6.3	6.0
13. Red Orach	8.7	7.3	6.7	7.8	7.3	5.3	7.8	6.5	5.3
AVERAGE	*8.5*	*8.1*	*7.1*	*8.2*	*8.2*	*7.0*	*7.7*	*7.1*	*5.9*
Brassica Greens									
14. Arugula	8.8	8.2	7.0	8.8	8.0	6.0	8.7	7.0	5.7
15. Tat-soi	8.5	7.2	6.3	8.5	7.0	6.7	8.3	7.0	6.7
16. Red Mustard	8.0	7.3	3.7	7.2	7.0	4.3	6.3	6.0	3.7
17. Red Kale	8.8	8.3	8.2	8.8	8.7	7.5	8.7	8.3	5.0
18. White feather kale	8.7	9.0	9.0	8.8	8.7	9.0	8.8	8.3	8.0
19. Red feather kale	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	8.3
20. Red Nagoya	9.0	9.0	9.0	9.0	9.0	8.3	9.0	9.0	7.2
21. White Nagoya	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	7.0
AVERAGE	*8.7*	*8.4*	*7.6*	*8.6*	*8.3*	*7.5*	*8.5*	*8.0*	*6.4*
OVERALL AVERAGE	***8.7***	***8.4***	***7.7***	***8.6***	***8.2***	***7.4***	***8.3***	***7.8***	***6.6***
LSD .05	***0.2***								

[1] red-green leafy lettuces.

[2] Visual quality was evaluated on a scale of 9 to 1, where 9=excellent, 1=unuseable; 6 is limit of salability.

Figure 1. Vase life (days) of Dendrobium orchids after treatment with high carbon dioxide atmospheres. Freshly harvested orchids were flown in from Hawaii. Orchids were exposed to 30% (4, 6 & 8 days), 45% (3, 5 & 7 days), 60% (1, 2 & 4 days) and 80% (0.5, 1 & 2 days) carbon dioxide in air at 13°C (55°F). Vase life was evaluated at 20°C (68°F)